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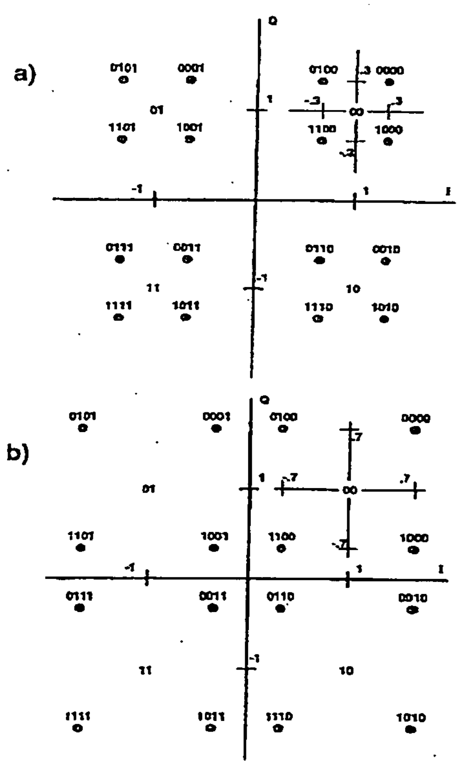
(54) Title: A HIERARCHICAL QAM TRANSMISSION SYSTEM WITH VARYING GROUPING FACTOR



(57) Abstract: A hierarchical QAM system allows the transmission of different sources by embedding the relative constellation points. A QAM transmitting system, includes a source of a level (1) and a level (2) data stream, each data stream carrying successive symbols. A hierarchical QAM transmitter, coupled to the level (1) and level (2) data stream source, generates a hierarchical QAM signal in which a level (1) symbol is represented by a data point in one of four quadrants in the I-Q plane, and a level (2) symbol is represented by the data point in one of four sub-quadrants surrounding a center point of the quadrant containing the level (1) data point. The level (2) data point is spaced away from the center point by a grouping factor set to more closely match the bit error rate performance of the level (1) and level (2) data streams.

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A HIERARCHICAL QAM TRANSMISSION SYSTEM WITH VARYING GROUPING FACTOR

FIELD OF THE INVENTION

The present invention relates to hierarchical quadrature amplitude modulation transmission systems.

BACKGROUND OF THE INVENTION

Hierarchical quadrature amplitude modulation (QAM) transmission systems are well known. For example, U.S. Patent 5,966,412, issued October 12, 1999 to Ramaswamy, discloses a modulation system which can remain backward compatible with older quadrature phase shift keyed (QPSK) receivers, while simultaneously further allowing additional data streams, for providing higher data rates or higher precision data, to be receivable by more advanced receivers. Fig. 1 is a block diagram illustrating a hierarchical QAM transmission system as disclosed in this patent. Fig. 1 discloses a data transmitter 100 coupled to a data receiver 300 via a transmission channel 200.

In Fig. 1, a first input terminal DATA 1 is coupled to source (not shown) of a first data signal, and a second input terminal DATA 2 is coupled to a source (not shown) of a second data signal. The first and second data signals may represent separate and independent data, or may represent related data signals, such as signals carrying respective portions of the same data signal (for increasing the throughput of the transmission system) or a elementary data portion and a supplemental data portion of the same data signal (for transmitting enhanced signals while maintaining backward compatibility with existing older receivers, as described in more detail below). The first input terminal DATA 1 is coupled to an input terminal of a first error detection/correction encoder 102. An output terminal of the first encoder 102 is coupled to an input terminal of a

of a second error detection/correction decoder 312. An output terminal of the second decoder 312 is coupled to a second data output terminal DATA 2'.

In operation, the first encoder 102 encodes the first data signal DATA 1 to provide error detection/correction capabilities in a known manner. Any of the known error detection/correction codes may be implemented by the encoder/decoder pairs 102/304, 108/312, and those codes may be concatenated, as described in the above mentioned patent. The first encoder 102 produces a stream of encoded bits representing the encoded first data signal DATA 1. The level 1 modulator 104 processes successive sets of two encoded data bits, each set termed a symbol, to generate a QPSK signal which lies in one of four quadrants in a known manner. Similarly, the second encoder 108 encodes the second data signal DATA 2 to provide error detection/correction capabilities in a known manner. The level 2 modulator 110 processes sets of two encoded data bits to also generate a QPSK signal which lies in one of four quadrants. One skilled in the art will understand that additional data signals (DATA 3, etc.) may be respectively error detection/correction encoded by additional encoders and additional QPSK modulators, (level 3, etc.) may be responsive to respective additional sets of two encoded data bits to generate additional QPSK signals. The QPSK signal from the level 1 modulator 104 is given a weight of 1; the QPSK signal from the level 2 modulator 110 is given a weight or gain of .5 by the variable gain amplifier 111; the third a weight of .25 and so forth. All the weighted QPSK signals are then combined into a single modulated signal by the signal combiner 106 and transmitted through a transmission channel 200.

The level 1 QPSK modulator 104 causes the combined signal to lie within one of four quadrants in response to the set of two encoded data bits from the first encoder 102. Each quadrant, in turn, may be thought of as divided into four sub-quadrants. The level 2 QPSK modulator 110 causes the combined signal to

DATA 2 are, thus, received, decoded and processed, and so forth. Such a transmission system operates by modulating a carrier in quadrature with what is seen as a constellation of permissible symbols, and is a form of quadrature amplitude modulation (QAM). Such a system is termed a hierarchical QAM transmission system because it may be used to transmit other levels of data signals, or other levels of detail in a single signal, while maintaining backwards compatibility with older receivers.

Fig. 2a is a diagram illustrating a constellation in the I-Q plane of permissible symbols for a hierarchical 16QAM transmission system, as illustrated in the above mentioned patent. In Fig. 2a, a first set of two bits determine which quadrant the generated symbol lies within. If the first two bits are "00" then the symbol lies within the upper right hand quadrant, and the level 1 modulator 104 produces I-Q signals such that I = 1 and Q = 1; if the first two bits are "01" then the symbol lies within the upper left hand quadrant, and the level 1 modulator 104 produces I-Q signals such that I = -1 and Q = 1; if the first two bits are "10" then the symbol lies within the lower right hand quadrant and the level 1 modulator 104 produces I-Q signals such that I = 1 and Q = -1; and if the first two bits are "11" then the symbol lies within the lower left hand quadrant and the level 1 modulator 104 produces I-Q signals such that I = -1 and Q = -1. This is indicated in Fig. 2a by the appropriate bit pair in the middle of the associated quadrant.

As described above, each quadrant may, itself, be considered to be divided into four sub-quadrants, as illustrated in the upper right hand quadrant in Fig. 2a. The second set of two bits determine which sub-quadrant the symbol lies within. The same mapping is used for determining the sub-quadrant as was described above for determining the quadrant. That is, if the second two bits are "00", then the symbol lies within the upper right hand sub-quadrant and the level 2 modulator generates an I-Q signal such that I = 1 and Q = 1; if the second

In accordance with principles of the present invention a QAM transmitting system, includes a source of a level 1 and a level 2 data stream, each data stream carrying successive symbols. A hierarchical QAM transmitter, coupled to the level 1 and level 2 data stream source, generates a hierarchical QAM signal in which a level 1 symbol is represented by a data point in one of four quadrants in the I-Q plane, and a level 2 symbol is represented by the data point in one of four sub-quadrants surrounding a center point of the quadrant containing the level 1 data point. The level 2 data point is spaced away from the center point by a grouping factor set to more closely match the bit error rate performance of the level 1 and level 2 data streams.

BRIEF DESCRIPTION OF THE DRAWING

Fig. 1 is a block diagram of a transmission system in accordance with principles of the present invention;

Fig. 2 is a diagram illustrating a constellation of permissible symbols for a hierarchical 16QAM transmission system;

Fig. 3a and c are more detailed block diagrams of respective portions of the transmission system illustrated in Fig. 1 and further including a gray code mapper, and Fig. 3b is a table containing data controlling the operation of the gray code mapper;

Fig. 4 is a more detailed block diagram of a portion of the transmission system illustrated in Fig. 1 illustrating the operation of differing error detection/correction codes for differing levels;

Fig. 5 is a diagram of a received constellation and Fig. 6 is a diagram of one quadrant of a received constellation distorted by the transmission channel;

Fig. 7 is a block diagram of circuitry for determining the center of gravity of a quadrant of a received constellation of data points;

a Q input terminal of the gray code mapper 112. An I output terminal of the gray mapper 112 is coupled to a second input terminal of the first adder 106(I) and a Q output terminal of the gray mapper 112 is coupled to a second input terminal of the second adder 106(Q). The variable gain amplifier 111, conditioned to have an attenuation factor of .5 and coupled between the gray code mapper 112 and the signal combiner 106, is not shown to simplify the figure.

In operation, the level 1 symbol, represented by the set of two encoded data bits, is received from the level 1 encoder 102 (of Fig. 1). The level 1 symbol is QPSK modulated by the level 1 modulator 104 to generate a set of I and Q component signals representing the quadrant of the modulated signal in a known manner. For example, if the symbol is 0, i.e. the two bits are 00, then the upper right hand quadrant is indicated (I = 1, Q = 1); if the symbol it 1, i.e. the two bits are 01, then the upper left hand quadrant is indicated (I = -1, Q = 1); if the symbol is 2, i.e. the two bits are 10, then the lower right hand quadrant is indicated (I = 1, Q = -1); and if the symbol is 3, i.e. the two bits are 11, then the lower left hand quadrant is indicated (I = -1, Q = -1). In a similar manner, level 2 symbol is QPSK modulated by the level 2 modulator 110 to generate a set of I and Q component signals representing the sub-quadrant of the modulated signal in a known manner. The level 2 modulator generates the modulated signal in exactly the same manner as the level 1 modulator 104, i.e. if the two bits are 00 (0), then the upper right hand sub-quadrant is indicated (I = 1, Q = 1); if the two bits are 01 (1), then the upper left hand sub-quadrant is indicated (I = -1, Q = 1); if the two bits are 10 (2) then the lower right hand sub-quadrant is indicated (I = -1, Q = 1); and if the two bits are 11 (3) then the lower left hand sub-quadrant is indicated (I = -1, Q = -1). This modulated signal is then weighted by .5 (not shown).

Such a mapping is reversible in the receiver 300 using a similar gray code mapper. Fig. 3c illustrates a portion of a receiver 300 including such a gray code mapper 314. In Fig. 3c, the output terminal of the reencoder 308 is coupled to an input terminal of the gray code mapper 314. An I signal from the subtractor 310 (of Fig. 1) is coupled to an I input terminal of the gray code mapper 314 and a Q signal from the subtractor 310 is coupled to a Q input terminal of the gray mapper 314. An I output terminal of the gray code mapper 314 is coupled to an I input terminal of the second decoder 312 and a Q output terminal of the gray code mapper 314 is coupled to a Q input terminal of the second decoder 312.

In operation, the reencoder 308 generates a signal which is an ideal representation of the received level 1 symbol. That is, if the received level 1 signal is determined to lie anywhere in the upper right hand quadrant, then the reencoder 308 produces a signal having the value 0; if anywhere in the upper left hand quadrant a value 1, if anywhere in the lower right hand quadrant a value 2 and if anywhere in the lower left hand quadrant a value 3. This symbol is supplied to a gray code mapper 314. Respective I and Q signals from the subtractor 310 are processed by the gray code mapper 314 in the manner described above, and illustrated in Fig. 3b. One skilled in the art will appreciate that the gray code mapper 314 in the receiver 300 operates identically to the gray code mapper 112 in Fig. 3a, and will perform the inverse function performed in the transmitter 100.

The use of gray code mappers (112 and 312) in the transmitter 100 and receiver 300 allow use of a constellation as illustrated in Fig. 2b, in the manner described above with respect to Fig. 3a. A transmission system using the gray code mapping function described above, to produce a constellation in which adjoining constellation points differ by no more than a single bit will increase the bit error rate of the system. Simulations have shown that using gray coding as described above will cut the number of level 2 bit errors in half. This provides an

connection of an inner decoder 312(I) and an inner encoder 312(O) As disclosed in the above mentioned patent, the outer encoder/decoder pairs implement a block coding technique, such as Hamming codes, Hadamard codes, Cyclic codes and Reed-Solomon (RS) codes, while the inner encoder/decoder pairs implement a convolutional code.

In Fig. 4, the coding used for the level 2 data stream is more powerful than the coding used for the level 1 data stream. More specifically, the convolutional code used in the inner encoder/decoder pair in the level 2 data stream is more powerful than the convolutional code used in the inner encoder/decoder pair in the level 1 data stream. For example, in a preferred embodiment, the first inner encoder/decoder pair, processing the level 1 data stream, implements a rate ½, constraint length 7 convolutional code punctured to a rate of ▯. The second inner encoder/decoder pair, processing the level 2 data stream, implements a rate ½ convolutional code without puncturing. The coding of the level 2 data stream is more powerful than that of the level 1 data stream. This more closely matches the bit error rate performance of the level 1 and level 2 data streams, and optimizes the performance of the transmission system as a whole.

As described above, and illustrated in Fig. 1, the level 1 demodulator 302 and decoder 304 cooperate to detect the DATA 1 signal from the received constellation. Then a reconstructed ideal signal, from reencoder 308, representing this detected DATA 1 signal is then subtracted from the received constellation, and ideally results in translation of the received constellation to form another constellation of the sub-quadrants within the detected quadrant. However, this translation operation is very sensitive to any mismatch between the actual "center point" of the quadrant as received, and the ideal center point (displaced by ± 1 from the origin of the level 1 constellation) assumed by the reencoder 308. Any mismatch in size between the received constellation and

An output terminal of the magnitude calculating circuit 324 is coupled to the reencoder 308.

In operation, the rotator 321 rotates all of the received values from whatever quadrant they were received in to the upper right hand quadrant in a known manner. Fig. 5 is a diagram of a received constellation and shows the locations of a plurality of successive received modulated data points. The received data points form scatters in the respective neighborhoods of the assumed locations of the received constellation points in all four quadrants. Fig. 6 is a diagram of the upper right hand quadrant of a received constellation all of whose data points have been rotated to this quadrant by the rotator 321. The quadrant illustrated in Fig. 6 represents a constellation which has been distorted by either deliberate pre-distortion of the transmitted constellation points and/or by the operation of the transmission channel 200.

The I component of the rotated data points from the rotator 321 is low pass filtered in the LPF 320 with a sliding moving average of n points. In the illustrated embodiment, the sliding moving average is calculated using the preceding 500 data points. The Q component of the rotated data points from the rotator 321 is similarly low pass filtered with a sliding moving average. One skilled in the art will understand that the low pass filters 320, 322 may also be constructed using respective IIR digital filters. The low pass filtering operation produces the respective I and Q components of the center of gravity of the received data points in the quadrant. The estimate of the magnitude of the center of gravity is calculated in the magnitude calculating circuit 324. For example if $r_i[n]$ is the filtered in-phase I component, and $r_q[n]$ is the filtered quadrature Q component, then the magnitude of the center of gravity is calculated as $M = \sqrt{r_i[n]^2 + r_q[n]^2}$. The magnitude of the center of gravity M should ideally be $\sqrt{2} = 1.4$. The magnitude of the ideal reconstructed signal from the reencoder 308 is adjusted in response to the magnitude of the

Referring to Fig. 8a, the gain of the variable gain amplifier (111 of Fig. 1) is conditioned to be .3. The resulting constellation points are spaced only .3 from the center point of the quadrant. One skilled in the art will recognize that in the constellation illustrated in Fig. 8a, the constellation points in a quadrant are further away from constellation points in other quadrants than in the constellation illustrated in Fig. 2a. Conversely, the constellation points within a quadrant are closer together than those illustrated in Fig. 2a. Such a system allows more accurate determination of which quadrant the level 1 data signal is in at the expense of less accurate determination of the constellation point of the level 2 data signal within the quadrant, thus, increasing the performance of the level 1 data stream and decreasing the performance of the level 2 data stream, when compared to the system of Fig. 2a..

Referring to Fig. 8b, the gain of the variable gain amplifier (111 of Fig. 1) is conditioned to be .7. The resulting constellation points are spaced .7 from the center point of the quadrant. One skilled in the art will recognize that in the constellation illustrated in Fig. 8b, the constellation points in a quadrant are closer to constellation points in other quadrants than in the constellation illustrated in Fig. 2a. Conversely, the constellation points within a quadrant are further apart than those illustrated in Fig. 2a. Such a system allows more accurate determination of the constellation point of the level 2 data signal within the quadrant at the expense of less accurate determination of which quadrant the level 1 data signal is in, thus, increasing the performance of the level 2 data stream and decreasing the performance of the level 1 data stream, when compared to the system of Fig. 2a..

By proper setting of the gain of the variable gain amplifier 111 (of Fig. 1), the grouping of the constellation points with each cluster may be placed optimally to more closely match the performance of the level 1 and level 2 data streams. It has been determined that for a 16QAM transmission system

CLAIMS

1. A QAM transmitting system, comprising:

a source of a level 1 and a level 2 data stream, each data stream carrying successive symbols; and

a hierarchical QAM transmitter, coupled to the level 1 and level 2 data stream source, for generating a hierarchical QAM signal in which a level 1 symbol is represented by a data point in one of four quadrants in the I-Q plane, and a level 2 symbol is represented by the data point in one of four sub-quadrants surrounding a center point of the quadrant containing the level 1 data point, wherein the level 2 data point is spaced away from the center point by a grouping factor set to more closely match the bit error rate performance of the level 1 and level 2 data streams.

2. The transmitting system of claim 1 wherein the center point representing the level 1 symbol is a predetermined distance from the origin of the I-Q plane, and the grouping factor is set to greater than one-half the predetermined distance.

3. The transmitting system of claim 2 wherein the grouping factor is between about .6 and about .7.

4. The transmitting system of claim 1 wherein the hierarchical QAM transmitter comprises:

a level 1 QPSK modulator, responsive to the level 1 data stream, for generating a level 1 QPSK signal representing the level 1 symbol;

a level 2 QPSK modulator, responsive to the level 2 data stream, for generating a level 2 QPSK signal representing the level 2 symbol; and

a QAM signal generator, for weighting the level 1 QPSK signal by a factor of 1, weighting the level 2 QPSK signal by the grouping factor, and combining

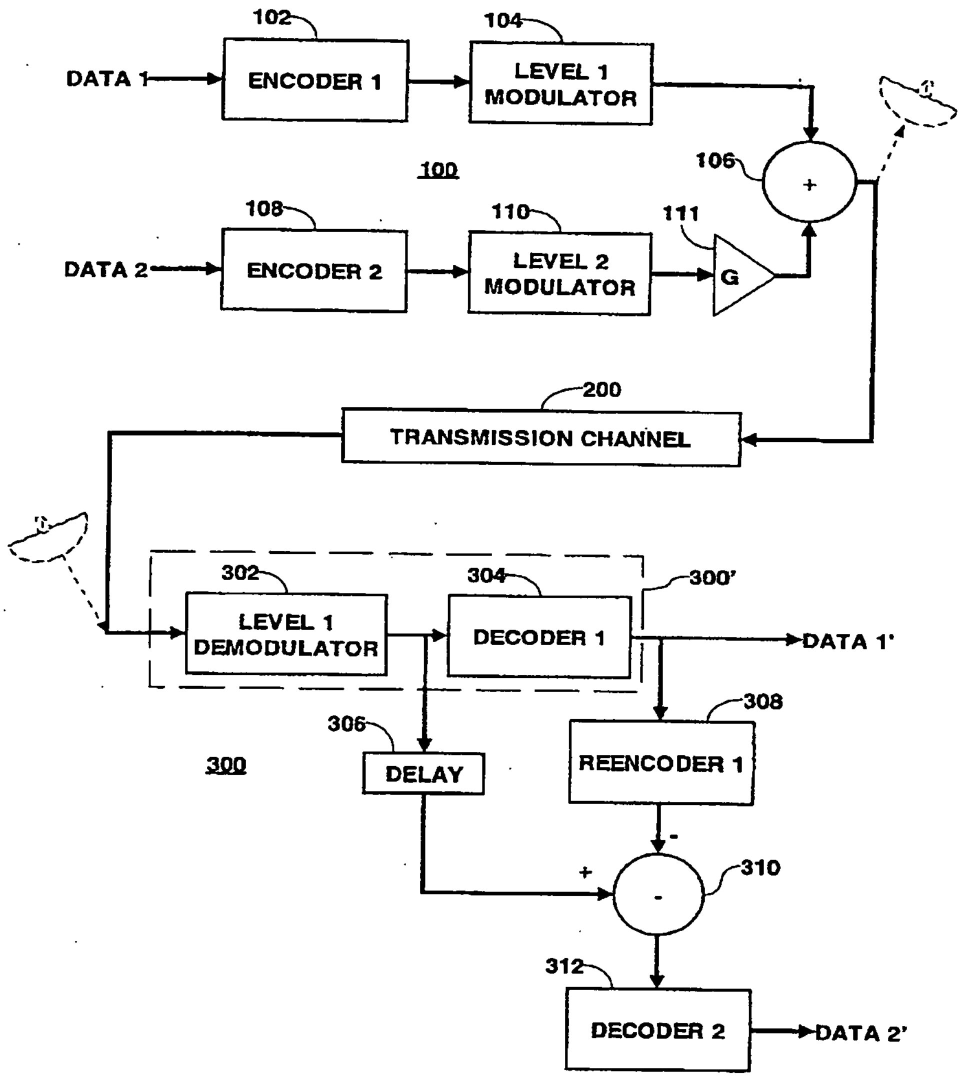
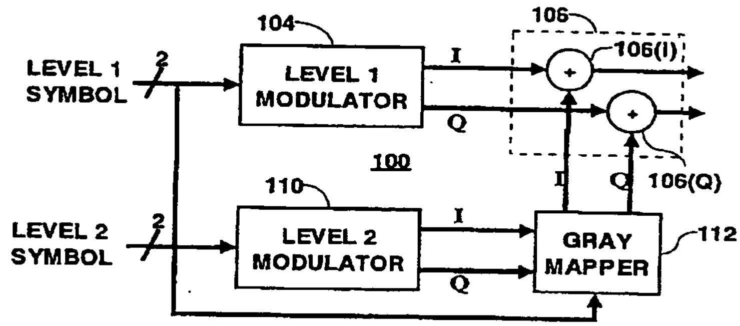

102
104
DATA 1
ENCODER 1
LEVEL 1 MODULATOR
106
+
100
108
110
111
DATA 2
ENCODER 2
LEVEL 2 MODULATOR
G
200
TRANSMISSION CHANNEL
302
304
300'
LEVEL 1 DEMODULATOR
DECODER 1
DATA 1'
308
306
300
DELAY
REENCODER 1
-
+
310
-
312
DECODER 2
DATA 2'

Fig. 1

a)



b)

Level 1 Symbol	Level 2 Iout	Level 2 Qout
0	Iin	Qin
1	-Iin	Qin
2	Iin	-Qin
3	-Iin	-Qin

c)

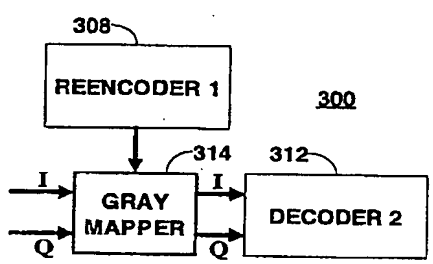


Fig. 3

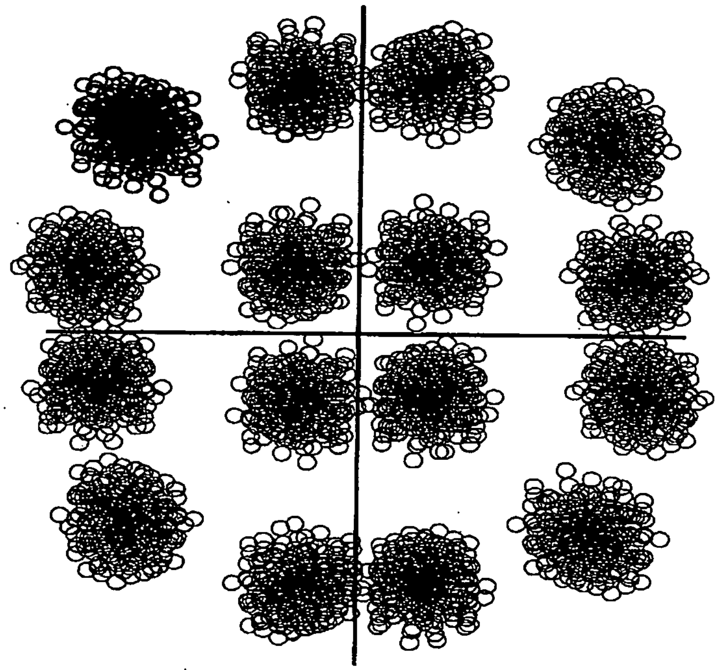
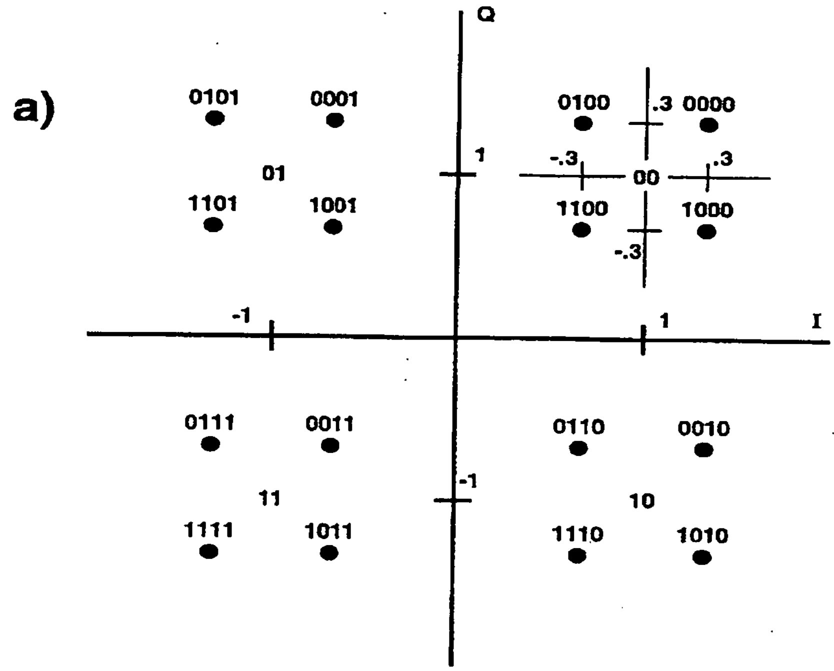


Fig. 5


a)
Q
I
0101
0001
0100
0000
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1101
1001
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1000
1
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.3
-.3
0111
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0010
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1111
1011
1110
1010

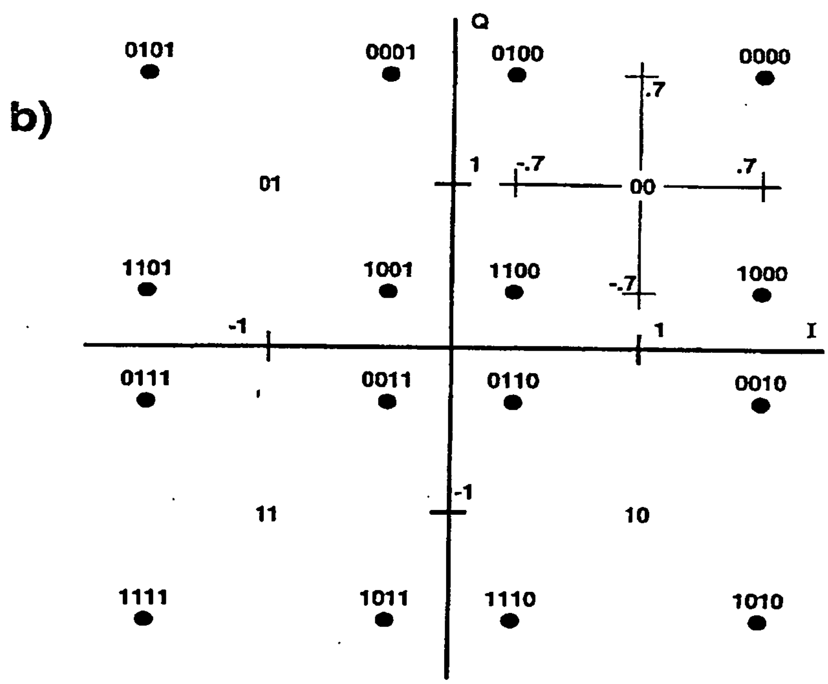
b)
Q
I
0101
0001
0100
0000
01
00
1101
1001
1100
1000
1
-1
.7
-.7
0111
0011
0110
0010
11
10
1111
1011
1110
1010

Fig. 8

INTERNATIONAL SEARCH REPORT

In ational Application No
PCT/US 00/32009

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KIM D ET AL: "PERFORMANCE OF MULTIRESOLUTION OFDM ON FREQUENCY-SELECTIVE FADING CHANNELS" GLOBAL TELECOMMUNICATIONS CONFERENCE (GLOBECOM),US,NEW YORK, IEEE, 3 November 1997 (1997-11-03), pages 16-20, XP000737503 ISBN: 0-7803-4199-6 page 17, right-hand column, line 30 - line 39	1-4
X	RUSSELL M ET AL: "TERRESTRIAL DIGITAL VIDEO BROADCASTING FOR MOBILE RECEPTION USING OFDM" WIRELESS PERSONAL COMMUNICATIONS,NL,KLUWER ACADEMIC PUBLISHERS, vol. 2, no. 1/02, 1995, pages 45-66, XP000589611 ISSN: 0929-6212 page 61, line 10 - line 11 figure 11	1-4

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